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In re Application of:
Hiroshi TOMIYASU et al
Serial No: 09/540,646
Filed: March 31, 2000
For: MAGNETIC RECORDING MEDIUM, AND THERMAL STABILITY MEASURING METHOD AND APPARATUS OF MAGNETIC RECORDING MEDIUM

Examiner: Holly Rickman

Art Unit: 1773

To: Commissioner for Patents
P.O. Box 1450
Alexandria, VA 22313-1450

TRANSMITTAL OF TRANSLATION OF PRIORITY DOCUMENT

Dear Sir:

We enclose herewith an English translation of previously submitted Japanese priority document no. JP 11-094391, filed March 31, 1999, on which we claim priority in the above referenced case.

Respectfully submitted,

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Date: November 12, 2004

[Name of Document] SPECIFICATION

[Title of the Invention] Magnetic Recording Medium

[Claims]

[Claim 1] A magnetic recording medium formed by successively laminating at least an under layer in this order and a magnetic layer on a substrate, wherein:

said under layer comprises at least a seed layer for finely dividing crystal particles of the magnetic layer, the seed layer comprises at least two or more layers of nonmagnetic films, and an intermediate layer formed of a material different from the material of said nonmagnetic film is interposed between the nonmagnetic films.

[Claim 2] The magnetic recording medium according to claim 1 wherein an under film for adjusting the crystal orientation of the magnetic layer is formed between said seed layer and said magnetic layer.

[Claim 3] The magnetic recording medium according to claim 1 or 2 wherein the film thickness of said nonmagnetic film is in a range of 100 to 550 angstroms.

[Claim 4] The magnetic recording medium according to any one of claims 1 to 3 wherein the film thickness of said intermediate layer is in a range of 5 to 50 angstroms.

[Claim 5] The magnetic recording medium according to any one of claims 1 to 4 wherein said intermediate layer comprises a nonmagnetic material which includes the same crystal structure as that of said nonmagnetic film.

[Claim 6] The magnetic recording medium according

to claim 5 wherein said intermediate layer comprises a material in which a crystal lattice surface interval does not match with that of said nonmagnetic film.

[Claim 7] The magnetic recording medium according to claim 12 wherein said nonmagnetic film comprises a material containing one alloy selected from a group consisting of NiAl, AlCo, FeAl, FeTi, CoFe, CoTi, CoHf, CoZr, NiTi, CuZn, AlMn, AlRe, AgMg, CuSi, NiGa, CuBe, MnV, NiZn, FeV, CrTi, CrNi, NiAlRu, NiAlW, NiAlTa, MiAlHf, NiAlMo, NiAlCr, NiAlZr, NiAlNb, and Al_2FeMn_2, and said intermediate layer comprises a material containing Cr.

[Claim 8] The magnetic recording medium according to claim 7 wherein said intermediate layer comprises a material formed of Cr and at least one type selected from a group consisting of Mo, V, W, and Ta.

[Claim 9] The magnetic recording medium according to claim 8 wherein said intermediate layer comprises an alloy mainly containing Cr and W.

[Detailed Description of the Invention]

[0001]

[Technical Field of the Invention]

The present invention relates to magnetic recording media such as a hard disk mounted on an external storage apparatus of a computer, particularly to a magnetic recording medium in which a seed layer is disposed between a substrate and an under film and a high coercive force and low noise are achieved.

[0002]

[Related Art]

As this type of magnetic recording medium, for example, a magnetic recording medium described, for example, in Japanese Patent Application Laid-Open No. 259418/1997 is proposed. The magnetic recording medium is formed by laminating a seed layer consisting of at least $Al_{1-x}Co_x$, and the like, a Cr or Cr alloy under film, and a Co alloy magnetic layer in this order on a substrate, and a high coercive force and low noise are achieved.

For the high coercive force in the magnetic recording medium, the seed layer enhances the crystal orientation property of surface (110) in a body-centered cubic crystal (bcc) of Cr or Cr alloy as the under film, and the crystal orientation property of surface (100) is enhanced and achieved, in which the easy axis of magnetization (c-axis) of the Co magnetic layer epitaxially grown on the under film is parallel with the inside of the plane.

Moreover, in this magnetic recording medium, since the thickness of the under film can be reduced by disposing the seed layer, the Co magnetic particles on the thinned under film are formed to be fine, so that the magnetic transition region (magnetic domain wall width) between recording bits can be reduced, and noises can be reduced.

[0003]

[Problem to be solved by the Invention]

However, when the film thickness of the seed layer is increased to obtain a high coercive force, the crystal particle diameter and particle diameter distribution forming the seed layer increase, and the crystal particle diameter and particle diameter distribution of the under film and magnetic layer formed on the seed layer also increase with the crystal growth, thereby causing a problem that the noise reduction cannot be realized.

Moreover, when the crystal particle diameter of the magnetic layer becomes very fine so as to reduce the noises, the magnetization becomes thermally unstable, thereby causing a phenomenon in which recorded signals are attenuated with time and finally disappear, that is, a phenomenon called thermal fluctuation. The noise has a trade-off relationship with the thermal fluctuation. When the crystal particle diameter of the magnetic layer becomes fine, the noises are reduced, but the signal attenuation by the thermal fluctuation increases, and the recorded signals are attenuated or easily disappear with the elapse of time. When the thermal fluctuation occurs, in addition to the signal attenuation (readback output decrease), the medium noise increases, or PW50 (the half pulse width of an isolated readback signal) value is deteriorated.

As described later, as the fine structure of the medium preferable for high-density recording, with the attaining of the fine magnetic layer crystal particles, it becomes important to reduce the dispersion of the particle

size (particle diameter distribution) and to depress the generation of the excessively fine particles susceptible to the influence of the thermal fluctuation.

[0004]

The present invention has been developed under the above-described background, and an object thereof is to provide a magnetic recording medium which achieves a high coercive force and a low noise and which is not easily influenced by thermal fluctuation.

[0005]

[Means for solving the Problem]

The present invention includes the following constitutions.

[0006]

(Constitution 1) A magnetic recording medium in which at least an under layer, and a magnetic layer are formed in this order on a substrate, wherein the under layer includes at least a seed layer for finely dividing crystal particles of the magnetic layer, the seed layer includes two or more layers of nonmagnetic films, and an intermediate layer formed of a material different from that of the nonmagnetic film is interposed between the nonmagnetic films.

[0007]

(Constitution 2) The magnetic recording medium according to the constitution 1 wherein the under layer for adjusting the crystal orientation of the magnetic layer is formed between the seed layer and the magnetic layer.

[0008]

(Constitution 3) The magnetic recording medium according to the constitution 1 or 2 wherein the thickness of the nonmagnetic film is in a range of 100 to 550 angstroms.

[0009]

(Constitution 4) The magnetic recording medium according to any one of the constitutions 1 to 3 wherein the film thickness of the intermediate layer is in a range of 5 to 50 angstroms.

[0010]

(Constitution 5) The magnetic recording medium according to any one of the constitutions 1 to 4 wherein the intermediate layer comprises a nonmagnetic material which includes the same crystal structure as that of the nonmagnetic film.

[0011]

(Constitution 6) The magnetic recording medium according to the constitution 5 wherein the intermediate layer comprises a material in which a crystal lattice surface interval does not match with that of the nonmagnetic film.

[0012]

(Constitution 7) The magnetic recording medium according to the constitution 6 wherein the nonmagnetic film comprises the material containing one alloy selected from a group consisting of NiAl, AlCo, FeAl, FeTi, CoFe, CoTi, CoHf, CoZr, NiTi, CuZn, AlMn, AlRe, AgMg, CuSi, NiGa, CuBe, MnV, NiZn, FeV, CrTi, CrNi, NiAlRu, NiAlW, NiAlTa, MiAlHf,

NiAlMo, NiAlCr, NiAlZr, NiAlNb, and Al2FeMn2, and the intermediate layer comprises the material containing Cr.

[0013]

(Constitution 8) The magnetic recording medium according to the constitution 7 wherein the intermediate layer comprises a material formed of Cr and at least one type selected from a group consisting of Mo, V, W, and Ta.

[0014]

(Constitution 9) In the magnetic recording medium according to the constitution 8 wherein the intermediate layer comprises an alloy mainly containing Cr and W.

[0015]

According to the constitution 1, the under layer includes at least the seed layer for finely dividing the crystal particles of the magnetic layer, the seed layer includes at least two or more layers of nonmagnetic films, and the intermediate layer comprising the material different from that of the nonmagnetic film is interposed between the nonmagnetic films. Therefore, the nonmagnetic film is an initial growth film with a small crystal particle diameter, and the crystal particle diameter of the under film and/or the magnetic layer formed on the nonmagnetic film is reduced, so that the magnetic transition region (magnetic domain wall width) can be reduced and uniformed, and noises are reduced. Moreover, for the coercive force, by setting the total of the thickness of the alloy films constituting the seed layer to

be the same as the film thickness of the seed layer constituted of the single layer of the alloy film, the high coercive force is maintained. Furthermore, by interposing the intermediate layer between the nonmagnetic films, the particle diameter distribution of the nonmagnetic film formed on the seed layer is reduced. When the under film and the magnetic layer are formed, the particle diameter distribution of the under film and magnetic layer is also reduced. Moreover, when no under film is formed, the particle diameter distribution of the magnetic layer is also reduced. Therefore, the generation of excessively fine particles susceptible to the influence of the thermal fluctuation can be suppressed, and the influence of the thermal fluctuation can be avoided. Specifically, as shown in Fig. 1, the conventional magnetic recording medium (curve B) disclosed in the Japanese Patent Application Laid-Open No. 259418/1997 includes the excessively fine particles (part B1) susceptible to the influence of the thermal fluctuation. On the other hand, in the present invention (curve A), since the excessively fine particles susceptible to the influence of the thermal fluctuation decrease (B1 → A1), the influence of the thermal fluctuation is not easily exerted. Moreover, in the present invention (curve A), since the particle diameter distribution is narrowed, the average particle diameter is reduced (B3 → A3), and the particles with large particle diameters are reduced (B2 → A2), the S/N ratio and PW50

(the mesial magnitude width of the isolated regeneration signal) are enhanced.

[0016]

Additionally, the nonmagnetic film constituting the seed layer is constituted of two or more layers. The number of nonmagnetic films can be set to two or more, such as three, four, or five, in consideration of the readback outputs, overwriting properties, and the like. Additionally, about three layers at maximum are usually preferable from the practical standpoint. Moreover, for the seed layer of the present invention, the intermediate layer is interposed between at least one pair of nonmagnetic films among two or morel layers of the nonmagnetic films. The intermediate layer has a function of temporarily interrupting the crystal growth of the nonmagnetic film. When there are three or more layers of nonmagnetic films, the intermediate layer is preferably disposed between the respective nonmagnetic films. In this case, when the number of layers of nonmagnetic films is n, n-1 intermediate layers are disposed. When there are three or more layers of nonmagnetic films, however, instead of disposing the intermediate layer among all the nonmagnetic films, the intermediate layer may be disposed between at least one pair of nonmagnetic films as occasion demands.

As the film constitution of the seed layer, the number of nonmagnetic films may further be increased such as nonmagnetic film-intermediate layer-nonmagnetic film

described later in the following embodiment, further nonmagnetic film-intermediate layer-nonmagnetic film-intermediate layer-nonmagnetic film, and nonmagnetic film-intermediate layer-nonmagnetic film-nonmagnetic film-intermediate layer-nonmagnetic film. Moreover, in two or more nonmagnetic films, the material and film thickness constituting each nonmagnetic film may be the same or different. Similarly, in two or more intermediate layers, the material and film thickness constituting each intermediate layer may be the same or different.

Furthermore, the intermediate layer of the nonmagnetic film has roles of interrupting the crystal growth of the nonmagnetic film under the intermediate layer, depressing the generation of the excessively fine particles of the nonmagnetic film (under layer, magnetic layer) formed on the intermediate layer, reducing the average crystal particle diameter, and reducing (narrowing) the particle diameter distribution.

[0017]

In the present invention, as described in the constitution 2, for the purpose of adjusting the crystal orientation of the magnetic layer, the under film may be formed between the seed layer and the magnetic layer.

Here, the under film is preferably formed of a material from which a high coercive force can be obtained. The under film can be constituted of one layer or two or more layers. As the under film, for example, a CrMo alloy,

a CrV alloy, a CrW alloy, and the like can be used. When the Cr alloy is used in this manner, and the magnetic layer comprises the Co alloy, the matching of the lattice surface interval with the under film is enhanced, so that the easy axis of magnetization of the magnetic layer easily turns into the surface. As a result, the coercive force and electromagnetic properties are enhanced. Moreover, when the same coercive force is obtained, the film thickness of the Cr alloy can be reduced as compared with the under film of Cr, so that the excessive increase of the particle size by the increase of the film thickness of the Cr alloy can be depressed, and the S/N ratio is improved.

[0018]

In the present invention, the intermediate film can also be formed between the under film and the magnetic layer as occasion demands, preferably in the position which abuts on the magnetic layer. This intermediate film is disposed for the purpose of enhancing the orientation of C-axis of the magnetic layer. The intermediate film is a nonmagnetic material, and the crystal system is preferably adapted to the crystal system of the magnetic layer. For example, in the CoPt-based magnetic layer, since the HCP crystal structure including the hexagonal closest packing crystal structure is constructed, the intermediate layer is provided with the HCP crystal structure, and CoCr, CoCrNb, CoCrPt, CoCrPtTa, and other alloys are preferable.

[0019]

In the present invention, as described in the constitution 3, from the standpoint of the fine and uniform crystal particle diameter of the nonmagnetic film, and the coercive force, the thickness of each nonmagnetic film constituting the seed layer is in a range of 150 to 550 angstroms, and the total film thickness is preferably in a range of 300 to 1100 angstroms.

When the thickness of each nonmagnetic film is less than 100 angstroms, the decrease of the coercive force is undesirably large. When the film thickness exceeds 550 angstroms, the crystal particle diameter and particle diameter distribution of the nonmagnetic film increase, the crystal particle diameter of the under film and/or the magnetic layer accordingly increase, and the noise unfavorably becomes high. Additionally, the total thickness of the nonmagnetic films constituting the seed layer can appropriately be adjusted in accordance with the coercive force to be obtained.

[0020]

In the present invention, as described in the constitution 4, from the standpoint of noise reduction, the film thickness of the intermediate layer is preferably in a range of 5 to 50 angstroms. Specifically, when the film thickness of the intermediate layer is less than 5 angstroms, the role of interrupting the crystal growth of the nonmagnetic film constituting the seed layer is not fulfilled, the upper-layer nonmagnetic film is formed with

the crystal growth of the lower-layer nonmagnetic film reflected thereon as it is, the crystal particle diameter and particle diameter distribution increase, the noise increases, and the influence by the thermal fluctuation is easily exerted. Moreover, when the film thickness exceeds 50 angstroms, the crystal particle diameter of the intermediate layer increases, the crystal particle diameter and particle diameter distribution of the upper-layer nonmagnetic film increase, and the noise undesirably increases.

[0021]

In the present invention, as described in the constitution 5, the intermediate layer preferably comprises the nonmagnetic material which includes the same crystal structure as that of the nonmagnetic film, in order to enhance the crystal growth of the magnetic layer.

[0022]

In the present invention, as described in the constitution 6, the intermediate layer preferably comprises the material in which the crystal lattice surface interval does not match with that of the nonmagnetic film, in order to set the crystal particle diameter of the upper-layer nonmagnetic film to be fine. Specifically, a difference of the crystal lattice surface interval between the intermediate layer and the nonmagnetic film is preferably of the order of 0.01 to 0.011 nm.

[0023]

In the present invention, as described in the constitution 7, the nonmagnetic film is not limited as long as the role of the seed layer (for obtaining the uniform and fine crystal particle diameter of the magnetic layer) is fulfilled, and preferably comprises one alloy selected from the group consisting of NiAl, AlCo, FeAl, FeTi, CoFe, CoTi, CoHf, CoZr, NiTi, CuZn, AlMn, AlRe, AgMg, CuSi, NiGa, CuBe, MnV, NiZn, FeV, CrTi, CrNi, NiAlRu, NiAlW, NiAlTa, MiAlHf, NiAlMo, NiAlCr, NiAlZr, NiAlNb, and Al_2FeMn_2. Moreover, the intermediate layer preferably comprises the material containing Cr. Above all, NiAl, CrTi, NiAlRu are preferable because the crystal particle diameter can be uniform and fine and the effect of reducing noises is high.

[0024]

In the present invention, as described in the constitution 8, the intermediate layer preferably comprises the Cr alloy formed of Cr and at least one type selected from the group consisting of Mo, V, W, and Ta. This is because in the above-described Cr alloy, the matching of the upper and lower seed layers is not deteriorated, only the particle diameter growth and distribution can be controlled, and there is preferably little dispersion of the magnetic properties. The content of at least one type selected from Mo, V, W, Ta in this Cr alloy is preferable in a range of 5 to 30 at%.

[0025]

In the present invention, as disclosed in the

constitution 9, the intermediate layer preferably comprises the alloy mainly containing Cr and W. This is because the dispersion of the magnetic properties is reduced and the productivity is stabilized by using the CrW alloy as the intermediate layer. When the CrW alloy is used, the content of W is preferably in a range of 5 to 30 at%. When the content is less than 5 at%, there is no effect of suppressing the particle growth of the seed layer or uniforming the particle diameter distribution. When it exceeds 30 at%, the matching with the upper seed layer is deteriorated, and the PW properties, S/N ratio, and coercive force are undesirably deteriorated. Additionally, other elements such as Nb may be contained by about 2 at% or less.

[0026]

Additionally, in the above-described magnetic recording medium of the present invention, the substrate material is not particularly limited. For example, a glass substrate, a crystallized glass substrate, an aluminum alloy substrate, a ceramics substrate, a carbon substrate, a silicon substrate, and the like can be used.

[0027]

In the magnetic recording medium of the present invention, the magnetic layer is not particularly limited.

Examples of the magnetic layer include the magnetic films mainly containing Co such as CoPt, CoCr, CoNi, CoNiCr, CoCrTa, CoPtCr, CoNiPt, CoNiCrPt, CoNiCrTa,

CoCrPtTa, CoCrPtB, and CoCrPtTaNb. The magnetic layer may be provided with a multilayered constitution (e.g., CoCrPtTa/CrMo/CoCrPtTa, and the like) by separating the magnetic film with the nonmagnetic film (e.g., Cr, CrMo, CrV, CrMnC, and the like) to reduce the noises. The magnetic layer for a magnetoresistive head (MR head) or a giant (large-sized) magnetoresistive head (GMR head) may comprise the Co-based alloy, and an impurity element selected from Y, Si, rare earth elements, Hf, Ge, Sn, and Zn, or the oxide of the impurity element. Moreover, the magnetic layer may include a granular structure in which magnetic particles such as Fe, Co, FeCo, and CoNiPt are dispersed in the ferrite-based, or iron-rare earth element-based nonmagnetic film containing SiO_2 or BN. Moreover, the magnetic layer may use an in-plane or vertical recording format.

[0028]

The protective layer, or the lubricant layer can be formed on the magnetic layer as occasion demands.

The protective layer is formed for the purpose of protecting the magnetic layer from the destruction by the contact sliding of the magnetic head. The protective layer can be constituted of one layer or two or more layers. Examples of the protective layer include a chromium film, a silicon oxide film, a carbon film, a hydrocarbon film, a carbon nitride film, a hydrocarbon nitride film, a zirconia film, a silicon nitride film, a silicon carbide film, and

the like. Additionally, the protective layer can be formed by the known film forming methods such as sputtering.

The lubricant layer is disposed for the purpose of reducing the resistance by the contact sliding with the magnetic head, and liquid lubricants such as perfluoropolyether are usually used.

[0029]

[Examples]

A magnetic recording medium of the present invention will further be described hereinafter with reference to examples.

<u>Example 1</u>

As shown in Fig. 2, the magnetic recording medium of the present example comprises a magnetic disk formed by successively laminating a seed layer 2, an under layer 3, an intermediate layer 4, a first magnetic layer 5, a nonmagnetic layer 6, and a second magnetic layer 7 on a glass substrate 1.

The glass substrate 1 is formed of a chemically reinforced aluminosilicate glass, and the surface is mirror-polished to provide a surface roughness Rmax = 3.2 nm, Ra = 0.3 nm.

The seed layer 2 comprises two layers of alloy film 21 and alloy film 23, and an intermediate layer 22, disposed between the alloy films, for interrupting the crystal growth of the alloy film 21, the alloy film 21 is an NiAl thin film (film thickness of 300 angstroms), the

intermediate layer 22 is a CrW thin film (film thickness of 30 angstroms), and the alloy film 23 is an NiAl thin film (film thickness of 300 angstroms). Additionally, the NiAl thin film constituting the alloy film 21 or 23 is constituted at a composition ratio of Ni: 50 at%, Al: 50 at%, and the CrW thin film constituting the intermediate layer 22 is constituted at a composition ratio of Cr: 90 at%, W: 10 at%.

The under layer is a CrMo thin film (film thickness: 100 angstroms), and is disposed to enhance the crystal structure of the magnetic layer. This CrMo thin film is constituted at a composition ratio of Cr: 90 at%, Mo: 10 at%.

Moreover, the intermediate layer 4 is a CoCr thin film (film thickness: 30 angstroms), and is disposed to enhance the orientation of C-axis of the magnetic layer. Additionally, this CoCr thin film is a nonmagnetic film with an HCP crystal structure at a ratio of Co: 65 at%, Cr: 35 at%.

The magnetic layer 5 is a CoCrPtTa alloy thin film (film thickness: 240 angstroms), and the contents of Co, Cr, Pt, Ta are Co: 72.5 at%, Cr: 16 at%, Pt: 8 at%, Ta: 3.5 at%.

The protective layer 6 prevents the magnetic layer from being deteriorated by contact with the magnetic head, and comprises a hydrocarbon film with a film thickness of 100 angstroms.

The lubricant layer 7 comprises a liquid lubricant

of perfluoropolyether, and this film moderates the contact with the magnetic head. Additionally, the film thickness is 8 angstroms.

[0030]

A method of manufacturing the magnetic disk constituted as described above will next be described.

First, the mirror surface (Rmax = 3.2 nm, Ra = 0.3 nm) was formed by precisely polishing the main surface of the glass substrate 1 chemically reinforced by ion exchange. Subsequently, the seed layer 2, under layer 3, intermediate layer 4, magnetic layer 5, and protective layer 6 were successively formed as the films on the main surface of the glass substrate 1 by the in-line sputtering. Subsequently, the protective layer 6 was dip-treated with the liquid lubricant of perfluoropolyether to form the lubricant layer 7 thereon, thereby obtaining the magnetic disk.

[0031]

For the measurement results of coercive force, S/N ratio, PW50 (the half pulse width of an isolated readback signal) of the obtained magnetic disk, the coercive force was 2800 Oe and satisfactory, the S/N ratio was 29.43 dB, and PW50 was 18.78 nsec and also satisfactory. Moreover, the output signal attenuation was -0.05 dB/decade at 100 kfci, 60°C, and Ku•V/kT indicating the thermal fluctuation properties was satisfactorily 110. Here, with respect to the thermal fluctuation resistance, the higher coercive force is preferable. When the value of the S/N ratio

increases, the noises are preferably reduced, and it is said that, for example, a difference of about 0.5 dB produces a difference in recording density of about 0.6 Gb/inch^2. The smaller PW50 (the half pulse width of the isolated readback signal) value is preferable, and it is said that a difference of about 0.6 nsec produces a difference in recording density of about 0.8 Gb/inch^2. The smaller output signal attenuation is preferable. When the value of Ku•v/kT increases, the thermal fluctuation resistance is preferably enhanced. Specifically, the value of Ku•v/kT is preferably 90 or more.

[0032]

Additionally, the coercive force, S/N ratio, PW50, output signal decay properties, and thermal fluctuation properties (Ku•v/kT) were measured by the following measuring methods.

[0033]

The measurement of the coercive force comprised: cutting the 8 mmϕ sample from the manufactured magnetic disk; applying the magnetic field toward the film surface; and performing measurement at the maximum external applied magnetic field of 10 kOe by a sample vibrating magnetometer.

[0034]

The S/N ratio was obtained by measuring the recording readback output as follows. The measurement comprised: using the magnetoresistive head (MR head) with a magnetic head flying height of 0.025 μm; setting the

relative rate of the MR head and the magnetic disk to 10 m/sec; and measuring the recording readback output in a linear recording density of 346 kfcl (the linear recording density of 346000 bits per inch). Moreover, the noise spectrum during signal recording regeneration was measured by the spectrum analyzer by setting the carrier frequency to 67.6 MHz, and the measurement band to 76.3 MHz. The MR head used in the measurement had a track width of 1.2/0.9 μm, and a magnetic head gap length of 0.27/0.15 μm on the write/read side.

[0035]

The PW50 (the half pulse width of an isolated readback signal) was measured by: extracting the isolated readback signal with the read/write tester (GUZIK) provided with the MR head for the PW50 measurement; and measuring the width of the isolated waveform in 50% of the peak value of the output signal to the ground (0) as PW50. Additionally, for the high recording density, the smaller PW50 is preferable. This is because more pulses (signals) can be written on the same area with the narrow pulse width. On the other hand, when the PW50 is large, the adjacent pulses (signals) interfere with each other, and the error appears during reading of the signal. This waveform interference deteriorates the error rate. This necessitates the setting of PW50 to 19.2 nsec or less.

[0036]

The measurement of the properties of output decay

was performed as follows.

In order to accurately evaluate only the signal attenuation by the thermal fluctuation of the magnetic recording medium without being influenced by a thermal off-track (a phenomenon in which the magnetic head deviates from the track on the magnetic recording medium by the thermal expansion of a head suspension, thereby causing signal attenuation), the MR head comprising the read/write element whose write track width is twice or more times as large as the read track width is prepared, and placed in the head/disc mechanism section in the system together with the magnetic disk as the obtained magnetic recording medium. Subsequently, the head/disk mechanism section is projected to an environmental tank in which a temperature can be controlled, and exposed to a high-temperature environment. When the inside of the environmental tank is stabilized at a preset temperature, by feeding a write signal to an MR head write element from a read/write circuit section, the signal is written to the magnetic disk. Subsequently, immediately after the signal is written, the signal written to the magnetic disk is read via an MR head read element, amplified in the read/write circuit section, and then measured in a signal evaluating section. The signal evaluating section records the amplitude value of the read signal at a constant time interval. The signal evaluating section performs measurement, for example, by using a spectrum analyzer.

For the measurement conditions, the temperature of the environmental tank is 60°C, and the recording density of the signal written to the magnetic disk is 100 KFlux/inch. Moreover, the head used in the measurement is an MR head which has a write track width of 12.0 μm, a read track width of 2.4 μm, a write gap length of 0.35 μm, a read gap length of 0.30 μm, and a read/write element part float-up amount of 20 nm.

[0037]

Moreover, the thermal fluctuation properties were measured as follows.

The activated magnetic moment (vIsb) as the product of the activation volume (v) and the saturation magnetization (Isb) of the magnetization reversal minimum unit was calculated by the fluctuation field (Hf) obtained by Waiting Time process. In the Waiting Time process, measurement is performed as follows. In the residual magnetization curve measurement, Hr(t) is measured by successively changing the waiting time of the magnetic field. The measurement comprises: placing the cut ϕ8 mm sample onto the sample signal type magnetometer (VSM) and applying a sufficiently large positive magnetic field to the sample; applying a micro negative magnetic field H1 to remove the magnetic field; measuring the residual magnetization M1; and again applying the positive magnetic field, applying the magnetic field H2 larger than H1 to remove the magnetic field, and subsequently measuring the

residual magnetization M2. The similar operation is repeated until Mi reaches the residual magnetization Mr. The obtained (Hi, Mi) is plotted to obtain the residual magnetization curve. The value of magnetic field H in M = 0 is defined as Hr (remanence coercive force).

Subsequently, the sufficiently large positive magnetic field is applied to the sample, the negative magnetic field H1 is applied for a waiting time of 15 seconds, the magnetic field is then removed, and the residual magnetization M1(15) is measured. Furthermore, the positive magnetic field is applied to the sample, the negative magnetic field H2 is applied for 15 seconds, the magnetic field is then removed, and the residual magnetization M2(15) is measured. The measuring operation is repeated until Mi(15) equals the residual magnetization Mr. The obtained (Hi, Mi) (15) is plotted to obtain the residual magnetization curve for the waiting time of 15 seconds. The H value in M = 0 is defined as Hr(15).

The similar operation is repeated for a waiting time of 15 seconds, 30 seconds, 60 seconds, 120 seconds, 240 seconds, 480 seconds (8 minutes), and the magnetic field Hr(15), Hr(30), Hr(60), Hr(120), Hr(240), Hr(480) in each waiting time is obtained. When this Hr(t) is plotted with respect to a time logarithm (ln t), Hr(t) linearly decreases, and the thermal fluctuation field Hf is obtained by the inclination dHr(t)/d(ln t). From Hf obtained in this manner, vIsb is calculated by the following equation.

$vIsb = kT/Hf$

Here, k denotes Boltzmann constant (1.38×10^{-16} erg/k), and T denotes an absolute temperature (K) being measured.

The activation volume v is used as the volume of the minimum unit of the magnetization reversal of the magnetic layer, and vIsb obtained by multiplying the volume by the saturation magnetization (Isb) is the magnetic moment amount of the minimum unit of the magnetization reversal.

Moreover, in the calculation of $v \bullet Ku/kT$, v and Ku need to be measured, but there is a relation of $Ku = (Hk \bullet Isb)/2$, and the following equation is calculated by further assuming $Hc0 = Hk/2$.

$v \bullet Ku = V \bullet Hk \bullet Isb/2 = vIsb \bullet Hk/2 = vIsb \bullet Hc0$

Here, Hc0 denotes Hc (coercive force) before Hc (coercive force) is deteriorated by the thermal fluctuation, and is Hc (coercive force) which can be obtained in a measurement time of 10^{-9}sec. Moreover, Hk denotes an anisotropic magnetic field owned by the minimum unit of the magnetization reversal, and vIsb denotes an activation magnetic moment.

Since Hc0 as Hc (coercive force) before the deterioration of Hc (coercive force) by the thermal fluctuation cannot substantially be measured, Sherlock equation is used to calculate Hc0 from Hc and vIsb. The Sherlock Law is an approximate equation dependent on the

measurement time of Hc obtained as a result of micro magnetic simulation, and is represented as follows.

$$Hc/Hc0 = 1-\{(kT/v \bullet Ku)\ln(f0 \bullet t)^{\wedge}0.735\}$$

Moreover, when the above-described assumption of Hc0 = Hk/2 is taken, the equation is modified as follows.

$$Hc/Hc0 = 1-\{(kT/vIsb \bullet Hc0)\ln(f0 \bullet t)^{\wedge}0.735\}$$

Here, k denotes Boltzmann constant (1.38×10^{-16} erg/k), T denotes the measurement absolute temperature, f0 denotes a vibration (fluctuation) factor (10^9Hz), t denotes a measurement time (600 sec), and vIsb denotes an activation magnetic moment (emu).

Since the values other than Hc0 are known in the above equation, Hc0 can be obtained by performing numeric analysis/calculation of Hc0.

Additionally, in the following examples and comparative examples, the coercive force, S/N ratio, PW50, output signal attenuation, and thermal fluctuation properties were measured based on the above-described measuring methods.

[0038]

Comparative Example 1

The magnetic disk was formed in a similar manner as Example 1 except that the seed layer 2 of Example 1 was formed as a single layer of NiAl thin film with a film thickness of 600 angstroms (Ni: 50 at%, Al: 50at%).

When the coercive force, S/N ratio, PW50, properties of output decay, Ku•V/kT of the magnetic disk

were measured, the coercive force was 2800 Oe, the S/N ratio was 29.63 dB, PW50 was 19.4 nsec, and a satisfactory result was not obtained for the PW50 value. Here, usually to raise the coercive force, a certain degree of thick under layer is necessary. However, when the film thickness of the under layer increases, the crystal particle diameter of the magnetic layer increases, and PW50 and S/N ratio are deteriorated. When the seed layer 2 of Example 1 is used, a desired coercive force can be obtained while maintaining the PW50 and S/N ratio.

Moreover, the magnetic disk of Comparative Example 1 indicated a high value of error rate as compared with Example 1. Furthermore, the output signal attenuation was -0.07 dB/decade under the measurement conditions of 100 Kfci and 60(C, and Ku•v/kT indicating the thermal fluctuation properties was 100 and deteriorated as compared with Example 1.

[0039]

Example 2 and Comparative Example 2

The magnetic disks were formed in the similar manner as in Example 1 and Comparative Example 1 except that the film thickness of the magnetic layer 5 in Example 1 and Comparative Example 1 was changed to 180 angstroms or less.

When the coercive force, S/N ratio, PW50, properties of output decay, and Ku•v/kT of the magnetic disk were measured, the following results were obtained.

[0040]

[Table 1]

	Coercive force (Oe)	S/N ratio (dB)	PW50 (nsec)	Signal decay (Db/decade)	Thermal fluctuation properties (Ku•v/kT)
Example 2	2650	30.9	17.9	-0.058	98
Comparative Example 2	2450	30.5	18.4	-0.077	80

[0041]

As shown in Table 1, the influence of the thermal fluctuation becomes remarkable as the film thickness of the magnetic layer decreases, and a difference of the output signal attenuation (-dB/decade) increases between a case (Example 2) in which the divided seed layer 2 of Example 1 is used and a case (Comparative Example 2) in which the single-layer seed layer of Comparative Example 1 is used.

As shown in Fig. 3, when the film thickness t of the magnetic layer (Mr denotes the residual magnetization) (Mrt = around 0.5 to 0.6) (in Example 1 and Comparative Example 1), the output signal decat (-dB/decade) has little difference by the difference of the seed layer. However, when the film thickness of the magnetic layer decreases (Mrt = around 0.4 to 0.3), the difference of the output signal attenuation (-dB/decade) increases between the case in which the divided seed layer is used (curve A) and the case in which the single seed layer is used (curve B), and the influence of thermal fluctuation becomes remarkable.

Moreover, usually in the fine division of the

magnetic particles, the value of Ku•v/kT is reduced, but in the present invention the particle diameter distribution of the magnetic particles is narrow and there is little number of excessively fine particles susceptible to the influence of thermal fluctuation. Therefore, even when the magnetic particles are finely divided, the value of Ku•v/kT is not reduced, and the thermal fluctuation resistance is satisfactory.

[0042]

Example 3

The magnetic disk was formed in the similar manner as Example 1 except that the magnetic layer 5 of Example 1 was formed of a first magnetic layer 51, a separating layer 52, and a second magnetic layer 53 and the protective layer 6 was formed of a first protective layer 61, and a second protective layer 62.

Additionally, the first and second magnetic layers 51 and 53 are formed of the same material of a CoCrPtTa alloy, and both have a film thickness of 120 angstroms. For the contents of Co, Cr, Pt, Ta of the magnetic layers, the first magnetic layer comprises Co: 72.5 at%, Cr: 16 at%, Pt: 8 at%, Ta: 3.5 at%, and the second magnetic layer comprises Co: 71 at%, Cr: 18 at%, Pt: 8 at%, Ta: 3 at%.

Moreover, the separating layer 52 interposed between the first magnetic layer 51 and the second magnetic layer 53 is a CrMnC thin film (film thickness: 30 angstroms) of a nonmagnetic material, and the composition

ratio is Cr: 97.95 at%, Mn: 2.00 at%, C: 0.05 at%.

Furthermore, the first protective layer 61 comprises a Cr film with a film thickness of 50 angstroms, and plays a role of a chemical protective film for preventing the magnetic properties of the magnetic layer from being deteriorated by oxidation. The second protective layer is a hydrocarbon film with a film thickness of 100 angstroms.

[0043]

When the coercive force, S/N ratio, PW50, properties of output decay, Ku•v/kT of the magnetic disk were measured, the coercive force was 2580 Oe, the S/N ratio was 30.7 dB, PW50 was 19.1 nsec, and satisfactory results were obtained. Moreover, the output signal attenuation was -0.08 dB/decade at 100 Kfci, 60°C, and the Ku•v/kT indicating the thermal fluctuation properties was also satisfactory at 90. Additionally, since the magnetic layer is divided and the particle diameter of the magnetic particle is reduced in Example 3, the influence of thermal fluctuation is easily exerted as compared with the magnetic recording medium of Example 1.

[0044]

Comparative Example 3

The magnetic disk was formed in the similar manner as Example 3 except that the seed layer 2 of Example 3 was formed of a single-layer NiAl thin film (Ni: 50 at%, Al: 50 at%) with a film thickness of 600 angstroms.

When the coercive force, S/N ratio, PW50, properties of output decay, Ku•v/kT of the magnetic disk were measured, the coercive force was 2580 Oe, the S/N ratio was 30.6 dB, PW50 was 19.6 nsec, the output signal attenuation was -0.10 dB/decade, and Ku•v/kT was 80.

[0045]

Examples 4 to 7, Comparative Examples 4 and 5

The magnetic disks were formed in the similar manner as Example 1 except that the film thickness of the alloy films 21, 23 constituting the seed layer 2 of Example 1 was changed to 90 angstroms (Comparative Example 4), 100 angstroms (Example 4), 250 angstroms (Example 5), 450 angstroms (Example 6), 550 angstroms (Example 7), and 600 angstroms (Comparative Example 5). The coercive force, S/N ratio, PW50, properties of output decay, Ku•v/kT of the magnetic disks were as follows.

[0046]

[Table 2]

	Each film thickness (Å)	Total film thickness (Å)	Coercive force (Oe)	S/N ratio (dB)	PW50 (nsec)	Signal decay (dB/decade)	Thermal fluctuation properties (Ku•v/kT)
Example 4	100	200	2536	29.3	18.7	-0.055	105
Example 5	250	500	2800	29.44	18.77	-0.050	110
Example 6	450	900	3567	29.45	18.2	-0.048	113
Example 7	550	1100	3542	28.9	18.0	-0.045	115
Comparative example 4	90	180	2214	28.7	19.1	-0.080	85
Comparative example 5	600	1200	3502	28.6	17.9	-0.046	115

[0047]

As shown in Table 2, the film thickness of the alloy films 21, 23 constituting the seed layer 2 is preferably in a range of 100 to 550 angstroms in view of the coercive force, S/N ratio (noise), PW50 magnetic properties, properties of output decay, and thermal fluctuation properties (Ku•v/kT).

[0048]

<u>Examples 8 to 10, Comparative Examples 6 and 7</u>

The magnetic disks were formed in the similar manner as Example 1 except that the intermediate layer 22 in Example 1 was CrMo (Mo: 10 at%), and the film thickness of this intermediate layer 22 was changed to 4 angstroms (Comparative Example 6), 5 angstroms (Example 8), 15 angstroms (Example 9), 50 angstroms (Example 10), and 60 angstroms (Comparative Example 7).

The coercive force, S/N ratio, PW50, properties of output decay, Ku•v/kT of the magnetic disks were as follows.

[0049]

[Table 3]

	Film thickness (Å)	Coercive force (Oe)	S/N ratio (dB)	PW50 (nsec)	Signal decay (dB/decade)	Thermal fluctuation properties (Ku•v/kT)
Example 8	5	2750	29.23	19.08	-0.055	105
Example 9	15	2800	29.43	18.78	-0.050	110
Example 10	50	2850	29.2	18.6	-0.045	115
Comparative example 6	4	2700	28.8	19.38	-0.060	100
Comparative example 7	60	2880	28.8	18.6	-0.045	118

[0050]

As shown in Table 3, the film thickness of the intermediate layer 22 is preferably in a range of 5 to 50 angstroms in view of the coercive force, S/N ratio, PW50, properties of output decay, and thermal fluctuation properties (Ku•v/kT).

[0051]

Additionally, the intermediate layer 22 (CrW (W: 10 at%)) in Example 1 was also subjected to the similar experiment, and the coercive force, S/N ratio, and PW50 indicated satisfactory values in the range of 5 to 50 angstroms. The alloy was different from the CrMo alloy in that the values were constant, the coercive force: 2820 Oe, noise: 29.3 dB, PW50: 18.6 nsec in the range of 5 to 50 angstroms. This is supposedly because the CrW alloy is a material whose crystal growth properties are not easily changed with respect to the film thickness change with the

seed layer as compared with other Cr alloys such as CrMo alloy. Specifically, there is little dispersion in the magnetic properties and the productivity is stable.

[0052]

Examples 11 to 16

The magnetic disks were formed in the similar manner as Example 1 except that the film material of the alloy films 21, 23 constituting the seed layer 2 of the example was changed to NiAlRu (Ni: 45 at%, Al: 50 at%, Ru: 5 at%) (Example 11), CrTi (Cr: 80 at%, Ti: 20 at%) (Example 12), CrNi (Cr: 60 at%, Ni: 40 at%) (Example 13), FeAl (Fe: 50 at%, Al: 50 at%) (Example 14), NiAlW (Ni: 50 at%, Al: 45 at%, W: 5 at%) (Example 15), and NiAlNb (Ni: 50 at%, Al: 45 at%, Nd: 5 at%) (Example 16).

The coercive force, S/N ratio, PW50, properties of output decay, and Ku•v/kT of the magnetic disks were as follows.

[0053]

[Table 4]

	Film material (Å)	Coercive force (Oe)	S/N ratio (dB)	PW50 (nsec)	Signal decay (dB/decade)	Thermal fluctuation properties (Ku•v/kT)
Example 11	NiAlRu	2850	29.2	18.97	-0.050	110
Example 12	CrTi	2700	29.7	18.8	-0.055	105
Example 13	CrNi	3300	29.2	18.5	-0.050	112
Example 14	FeAl	2600	28.8	19.0	-0.050	110
Example 15	NiAlW	3200	29.0	19.1	-0.060	103
Example 16	NiAlNd	3100	29.2	19.2	-0.062	100

[0054]

As shown in Table 4, it is seen that for the film materials of the alloy films 21, 23, NiAlRu, CrTi, CrNi are particularly preferable among the materials shown in Table 4 in view of the coercive force, noise, PW50 magnetic properties, properties of output decay, and thermal fluctuation properties (Ku•v/kT).

[0055]

Examples 17 to 19

In the similar manner as Example 1, 100 pieces of each magnetic disk were formed except that the film material of the intermediate layer 22 in Example 1 was changed to CrMo (Cr: 90 at%, Mo: 10 at%) (Example 17), CrV (Cr: 80 at%, V: 20 at%) (Example 18), and CrTa (Cr: 95 at%, Ta: 5 at%) (Example 19).

The coercive force, S/N ratio, PW50, properties of

output decay, and Ku•v/kT of the magnetic disks were as follows.

[0056]

[Table 5]

	Film material	Coercive force (Oe)	S/N ratio (dB)	PW50 (nsec)	Signal decay (dB/decade)	Thermal fluctuation properties (Ku•v/kT)
Example 17	CrMo	2750~2850	29.1~29.5	18.4~19.2	-0.040~-0.055	100~115
Example 18	CrV	2750~2850	29.2~29.8	18.4~19.2	-0.040~-0.055	100~115
Example 19	CrTa	2700~2870	28.5~29.3	18.8~19.4	-0.040~-0.060	100~120
Example 1	CrW	2780~2850	29.2~29.4	18.4~18.8	-0.045~-0.055	105~115

[0057]

As shown in Table 5, when the film material of the intermediate layer 22 is CrW, there is little dispersion in magnetic properties and the productivity is also preferably stable. This is because CrW has a good lattice matching with the seed layer as compared with the Cr alloy films such as CrMo, and the CrW film thickness change causes little change of properties.

[0058]

[Effect of the Invention]

As described above, according to the present invention, there can be obtained the magnetic recording medium which achieves a high coercive force and low noise and which is not easily influenced by thermal fluctuation.

[Brief Description of the Drawings]

[Fig. 1]

It is an explanatory view showing the action of a

seed layer of the present invention.

[Fig. 2]

It is a schematic diagram showing a magnetic disk according to one embodiment of the present invention.

[Fig. 3]

It is an explanatory view showing a relation between the film thickness of a magnetic layer and the influence of thermal fluctuation.

[Description of Reference Numerals]

1 glass substrate 1

2 seed layer

3 under film

4 intermediate layer

5 magnetic layer

6 protective layer

7 lubricant layer

21 nonmagnetic film

22 intermediate layer

23 nonmagnetic film

[Name of Document] ABSTRACT

[Abstract] There is provided a magnetic recording medium which achieves a high coercive force and low noise and which is not easily influenced by thermal fluctuation.

[Solution Means] In a magnetic recording medium constituted by forming at least an under layer and a magnetic layer in this order on a substrate,

the under layer includes a seed layer 2 for finely dividing the crystal particles of the magnetic layer, the seed layer 2 includes at least two or more layers of nonmagnetic films 21, 23, and an intermediate layer 22 formed of a material different from the materials of the nonmagnetic films 21, 23 is interposed between the nonmagnetic films 21 and 23.

[Selected Drawing] Fig. 2

Fig. 1

Particle number

Small

Particle diameter

Large

Fig. 2

Lubricant layer 7

Protective layer 6

Magnetic layer 5

Intermediate layer 4

Under film 3

Seed layer 2

Under layer

Nonmagnetic film 23

Intermediate layer 22

Nonmagnetic film 21

Glass substrate 1